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13. ABSTRACT (Maximum 200 words)

A promising ultrasonic non-destructive evaluation (NDE) technique for the characterization of the interphase is given for a single fiber composite. The formal solution to the formulated problem is found via the normal mode expansion method. A computer program is developed for the calculation of the formal solution and its validity is confirmed by two methods: limited case analysis and energy balance analysis. In an attempt to solve the inverse problem of assessing the input parameters from the output parameters, one or more of the input parameters (interphase properties) are assumed to be known as their respective nominal values. For such simplified cases, a graphical technique for solving the inverse problem is developed and demonstrated. Finally, the interphase thickness parameter is shown to be predicted through linear and non-linear multiple regression with high accuracy.

14. SUBJECT TERMS

Composite interphases; Ultrasonics; Nondestructive evaluation; Inverse analysis; NDE; NDT; NDI

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INTRODUCTION

This report documents the accomplishments to date on the subject contract. The research efforts have focused on:

1. The theoretical formulation and computer modeling of two-dimensional scattering problems in composite materials; and

2. The development of intelligent unsupervised pattern recognition methods for various ultrasonic waveforms.

These two efforts are conjoined in testing the efficacy of the pattern recognition methods on data currently being generated via our multiple-fiber two-dimensional scattering model, as well as in further developing the multiple-fiber two-dimensional scattering model itself.
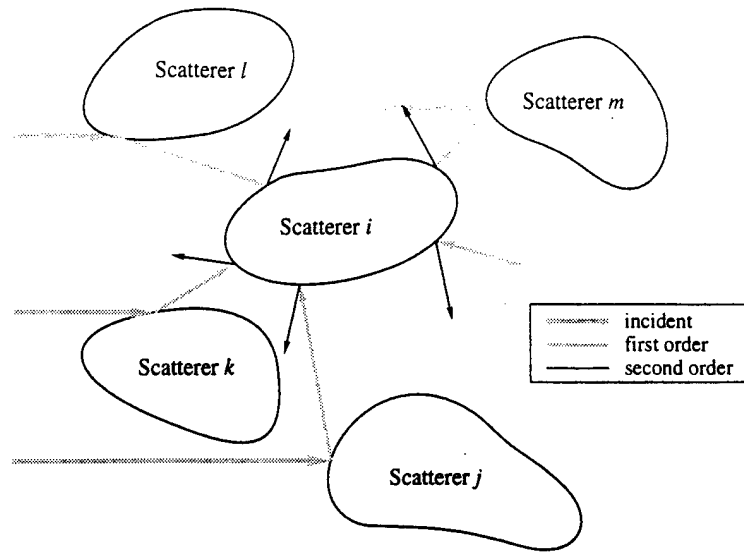
In previous research, a computational model for a single-fiber model was developed, and unsupervised pattern recognition methods were used to classify wave fields that were measured following the introduction of ultrasonic waves into composite specimens. These wave fields contained information about the physical and geometric properties of fiber composite interphases. These methods classified the wave fields into tightly clustered hierarchical groups (clusters) or classes that provided an excellent means of quantitatively determining the interphase thickness. (See Significant Publications on page 4 of this report.)

Currently, theoretical formulations and computer modeling of multiple-fiber two-dimensional multiple-scattering problems are underway. In addition, data now being generated via the multiple-fiber model are being used to test the ability of similar unsupervised pattern recognition methods for the multiple fiber case. The multiple fiber case, moreover, offers the opportunity of testing the accuracy and effectiveness of the unsupervised methods to classify signals (eg., wave fields) not only by physical and geometric properties of the individual fibers but also by fiber volume fraction and the geometric arrangement of a set of fibers (scatterers).

ACCOMPLISHMENTS TO DATE

1. We have completed the theoretical formulation for the steady state response of a general two-dimensional multiple-fiber scattering problem involving an arbitrary number of scatterers of known scattering characteristics. The multiple-scattering formulation in essence follows the physical "order of scattering" approach as sketched in our original proposal, which is also presented in Fig. 1.

Figure 1 depicts the first two "order of scattering" stages in a multiple scattering problem. The incident wave is scattered by the scatterers to generate the first order scattered

Fig. 1 Conceptual depiction of the first two order scattering stages in a multiple scattering problem.

waves; these first order scattered waves are then further scattered by the scatterers to generate the second order scattered waves, and so on. The total wave in the steady state is obtained by summing all the orders (from zero, being the incident wave, to the infinity) of waves. Thus far, this has been completed for shear waves.

2. We have completed the implementation of automatic recursive clustering for the unsupervised clustering algorithm. The goal of this first experiment was to test the viability of the algorithm to classify a displacement wave field into the correct relative fiber thickness categories.

Recently, we have designed three new experiments for testing the viability of the clustering methods for classifying a wave field by (a) material properties, (b) geometrical arrangement of multiple fibers and (c) fiber spacing.

DOCUMENTATION

The following documents are in preparation:

- Multiple Scattering of Elastic Waves in Composites, I—Theory for SH Waves.

- Multiple Scattering of Elastic Waves in Composites, II—Theory for P and SV Waves.

- Multiple Scattering of Elastic Waves in Composites, III—Implementation for SH Waves.

- Multiple Scattering of Elastic Waves in Composites, IV—Implementation for P and SV Waves.

- Unsupervised Classification of Fiber Composite Interphases: Single Fiber Case.

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- Unsupervised Classification of Fiber Composite Interphases: Multiple Fiber Case.

SIGNIFICANT PUBLICATIONS

The November 1995 edition of the journal *Ultrasonics* will be a special issue that will focus on interphase characterization. Our work will be featured prominently in that issue: we shall have three papers, namely,

1. Formulation and Its Energy Balance Verification for Ultrasonic Nondestructive Characterization of Single Fiber Composite Interphase;

2. Database Generation and Parametric Study for Ultrasonic Characterization of Single Fiber Composite Interphase; and

3. Multiparameter Statistical Determination of Single Fiber Composite Interphase Properties.

FUTURE DIRECTIONS AND EXPERIMENTS

1. Complete the computer implementation of the multiple-scattering formulation for longitudinal waves.

2. Perform extensive and systematic computation for data base generation. The combination of all the following needs to be considered: the number of fibers, the geometrical arrangements of the fibers, and the various physical properties of the interphase.

3. Conduct future experiments for testing the pattern recognition methods in cases where two variables such as interphase thickness and geometrical fiber arrangement are allowed to vary.